Mid-Frequency Environmental and Acoustic Studies from SW06, and Applications to Asian Littoral Waters

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LONG-TERM GOALS

(1) To develop a basis for the Navy to make decisions on what environmental parameters to measure, to what spatial and temporal scale they should be measured, and how to best select frequencies for sonar design. Emphasis is on the mid- to high-frequency range defined as frequencies nominally between 1 and 20 kHz.

(2) A second goal relates to engagement with the Naval Research Laboratory, the Korean Agency for Defense Development (ADD), Hanyang University (HYU), to undertake collaborative research programs in shallow water acoustics in Asian littoral waters.

OBJECTIVES

The primary objective this year was analyze measurements of spatial coherence from Shallow Water 06 (SW06) obtained by the PI in August 2006, and model these data based on measured environmental processes.

A second objective was to complete the examination of data gathered off the coast of Korea with the U.S. NRL, ADD and HYU that occurred in August 2008, as part of the Transverse Acoustic Variability Experiment (TAVEX).

APPROACH

The main set of spatial coherence data originate from the geometry shown in Fig. 1, which is from SW06. An acoustic source (1-20 kHz) was deployed at depth 40 m from the stern of the R/V *Knorr*, and signals were recorded on the moored receiving array (MORAY). The location of the MORAY (39.0245 N, 73.0377 W, depth 80 m) defined the central (mid-frequency) site for SW06 experimental observations, and propagation measurement were made at fixed stations that allowed for the sampling of acoustic propagation effects at different ranges and directions with respect to the MORAY. Key environmental data include water column sound speed and sea surface conditions, both of which are used in a scattering-based modeling approach [1] for short range measurements (100-500 m), and an approach based on a rough surface parabolic wave equation code for longer range (1-10 km).

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14. ABSTRACT

To develop a basis for the Navy to make decisions on what environmental parameters to measure, to what spatial and temporal scale they should be measured, and how to best select frequencies for sonar design. Emphasis is on the mid- to high-frequency range defined as frequencies nominally between 1 and 20 kHz.

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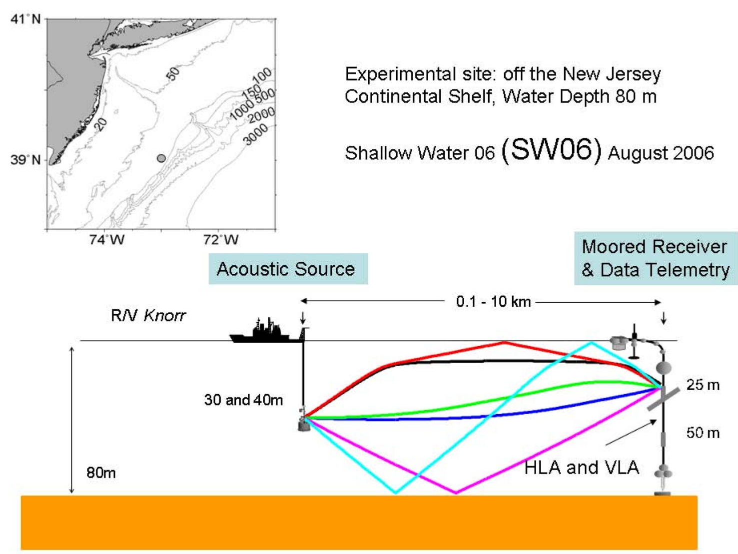

Figure 1 Measurement geometry for horizontal and vertical spatial coherence measurement versus range from source during SW06 (August 2006).

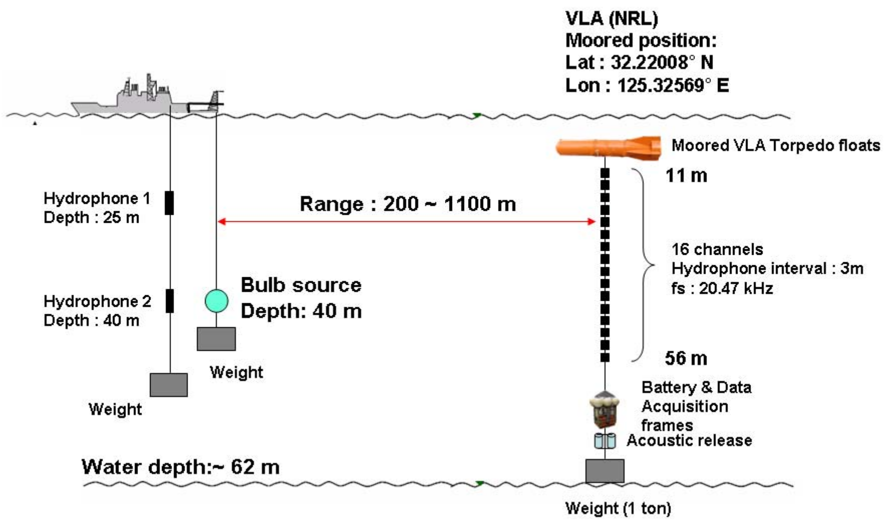

Figure 2 Measurement geometry for broad band propagation measurements during TAVEX (August 2008).

WORK COMPLETED

A study of vertical spatial coherence associated with forward scattering from the sea surface was completed with results summarized in Dahl, 2009. This study demonstrated the important role of a downward refracting sound speed profile on enhancing the spatial coherence over that which would be expected for the same sea surface conditions but with an iso-speed profile. The effect, called angular compression, is physically modeled and parameterized. A related study concerns much longer range spatial coherence, for which the entire channel is included rather than an isolated surface bounce path as in the aforementioned work. Here, vertical spatial coherence was modeled using a the RAM [2] parabolic wave equation (PE) code, modified to include the effects of a rough sea surface based on the approach outlined in [3]. These results were presented at Portland meeting of the Acoustical Society of America in June 2009.

Results of the August 2008 experiment in Korea have been analyzed with results presented at the TAVEX workshop held in conjunction with the Korean Acoustical Society meeting in September 2009.

RESULTS

Owing to space restrictions, this section will be limited to the short range spatial coherence study from SW06. The key results from this study are summarized in Figs. 3 and 4.

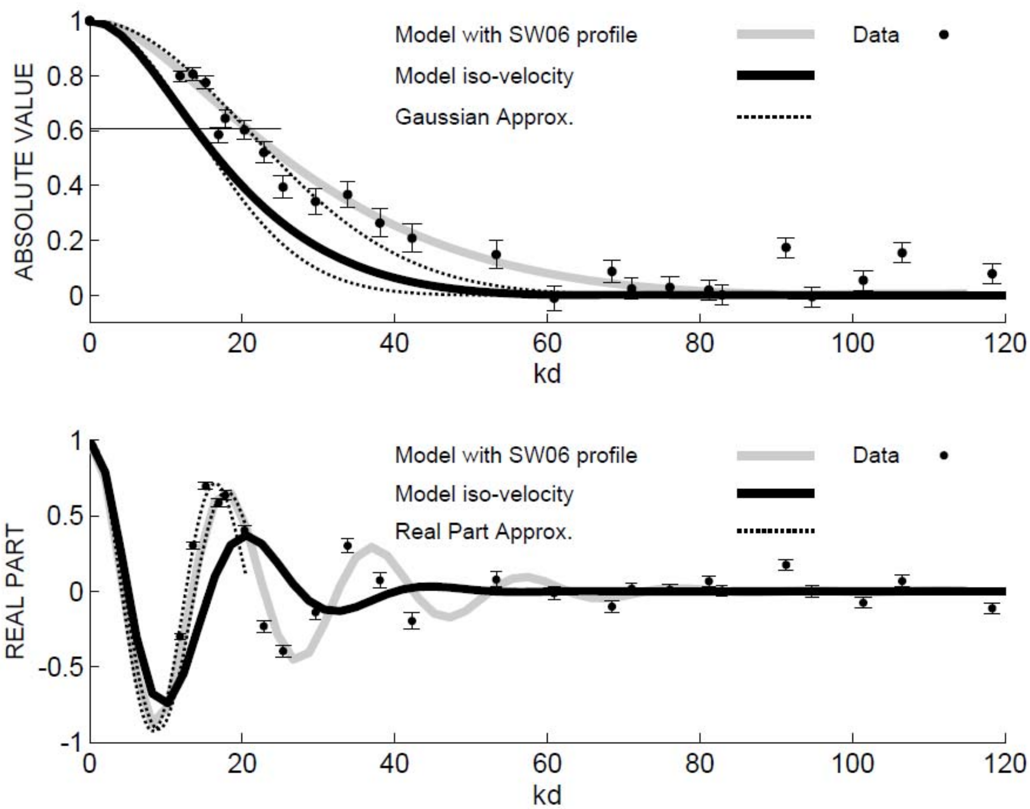

Figure 3 (a). Estimates of the absolute value of vertical spatial coherence with error bars based on 160-ping average plotted as function of normalized receiver separation kd for center frequencies 14, 16, 18, and 20 kHz. Solid lines represent a model for the absolute value based on the SW06 profile or iso-velocity profile. Two dotted lines represent Gaussian approximations for coherence magnitude; the horizontal line corresponds to magnitude coherence equal to $e^{-1/2}$. (b) Estimates of the real part of vertical spatial coherence (error bars are those in Fig. 3 (a) multiplied by $\sqrt{2}$) plotted as function of normalized receiver separation kd for center frequencies 14, 16, 18, and 20 kHz. Solid lines represent a model for the real part based on the SW06 profile or iso-velocity profile. Two dotted lines represent approximations for coherence real part as discussed in Dahl (2009).

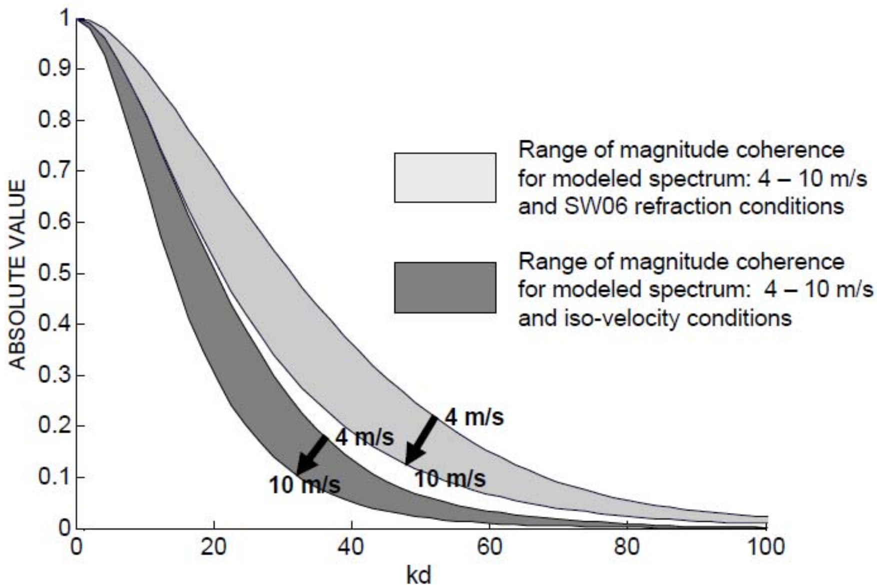

Figure 4. Estimates of the absolute value of vertical spatial coherence plotted as function of normalized receiver separation kd for center frequency 20 kHz. The lighter gray area represents a family of model coherence curves based on the SW06 sound speed profile. The upper and lower boundaries of the filled area represent specific model coherence curves based on a model-generated sea surface wave number spectra that corresponds to wind speeds of 4 m/s and 10 m/s, respectively. The darker gray area has boundaries defined in the same manner, but curves are based on an iso-velocity profile.

The primary conclusions that emerge from this study are:

1. In terms of sea surface forward scattering, the thermocline conditions of SW06 and associated strong downward refraction compresses the distribution of received vertical arrival angles associated with rough surface scattering, and thereby increases vertical coherence.

2. Models for the vertical spatial coherence that incorporate both sea surface roughness and the downward refraction conditions compare well with observations in both magnitude and phase. The models show how refraction produces an increase in vertical coherence magnitude that is on the level of, or exceeds, that associated with a large change in sea surface wave conditions. For a given sea surface roughness, the opposite (decreased vertical coherence) is expected to occur for upward refracting conditions.

3. A simplified model predicts the compression effect based on Snell's law, with the sound speed difference between sea surface and receiver, and surface grazing angle combined into a parameter referred to as the compression factor that predicts the change coherence length due to refraction.

IMPACT/APPLICATIONS

The SW06/LEAR data set, with its emphasis on simultaneous, co-located environment and acoustic measurements, will assist the Navy in making rational decisions on what environmental parameters to measure, to what spatial and temporal scale they should be measured, and how to best select frequencies for sonar design. The acoustic field spatial coherence is one of the most fundamental measures of shallow water acoustic propagation, with relevance to shallow water reverberation, beam forming.

RELATED PROJECTS

This research is integrated together with those from several PIs involved in the SW06/LEAR program.

REFERENCES

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PUBLICATIONS

P. H. Dahl, Observations and modeling of angular compression and vertical spatial coherence in sea surface forward scattering, ***J. Acoust. Soc. Am.,*** 2009. [in press, refereed]